RESEARCH DEPARTMENT

FINAL REPORT ON THE LONG-SLOT AERIAL

Report No. E-039/3

(1957/16)

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SUMMARY

In two earlier reports (E-039[1] issued in May 1951, and E-039/2[2] issued in January 1952) the results of tests on a small-scale model of a long-slot aerial are described; the measurements were made at a frequency of 500 Mc/s. Tests on a larger-scale model were later made at a frequency of 200 Mc/s in order to achieve greater accuracy. The results of this last series of tests were not published when the investigation had been completed, mainly owing to the fact that by this time both the electrical and structural requirements had been changed; as a result it was decided not to use the long-slot aerial at any of the B.B.C. stations proposed at the time. For the sake of completeness it has now been decided to publish the results obtained with the larger-scale model. The report that follows was written in December 1953 and is therefore in terms of the requirements existing at that time.

The original requirement was for a long-slot aerial having a substantially circular horizontal radiation pattern, for use in Band I at medium-power television stations. The measurements on the larger-scale model indicated that the bandwidth was somewhat less than had been expected from the earlier higher-frequency measurements. The required bandwidth could be obtained only with difficulty in the lowest frequency channel, using a complicated compensating circuit. Moreover, the use of the aerial would have involved mechanical difficulties, mainly owing to the fact that two tiers would be required, and that the Band I aerial would ultimately support a Band III aerial. These requirements were not foreseen when the work was begun. It was decided not to proceed further with the aerial for Band I, but it might well have applications at higher frequencies, for instance in Band II or Band III.

1. INTRODUCTION

Research Department Report No. E-039[1] summarized preliminary work on an omni-directional long-slot aerial. It was thought that this aerial might be suitable for medium-power television stations radiating horizontally-polarized waves. The experimental results indicated that a horizontal radiation pattern uniform to ±1·5 dB could be achieved, and that the mean gain would be approximately 4 dB, ignoring losses. (This was at the time thought to be adequate, but a higher gain was eventually called for — see Section 2.2). It was, however, uncertain whether an acceptable impedance-frequency characteristic could be achieved. The uncertainty was occasioned in part by the inaccuracy of the impedance measurements, which were made at frequencies in the neighbourhood of 500 Mc/s, and partly by the fact that the precise requirements were not known at the time.

One of the advantages offered by the long-slot aerial was the possibility of modifying it by the addition of reflectors so as to give a directional horizontal radiation pattern. This procedure would have enabled the same basic aerial to be used at all medium-power stations, parasitic elements being used to modify the horizontal radiation pattern where required. The results summarized in Research Department Report No. E-039/2[2] showed that a number of different shapes of radiation pattern could be obtained in this way. Moreover it was found that the presence of the parasitic elements resulted in a useful improvement in the impedance-frequency characteristic; this effect is not yet understood.

Following an international conference it was decided that at the two stations requiring a directional horizontal radiation pattern, Rowridge and North Hessary Tor, the polarization would be vertical; as a result a directional form of the long slot was no longer required. The conclusion of the investigation was therefore concerned with the omnidirectional form of the aerial, with a view to its use at Divis, Meldrum and Pontop Pike.

A provisional mechanical design was evolved in consultation with Building Department and P. & I.D., and a new model was constructed. This was larger than the previous model, being designed for frequencies in the neighbourhood of 200 Mc/s, so as to permit the inclusion of mechanical details that might affect the performance, and to improve the accuracy of impedance measurements. This report summarizes the work on this model.

2. REQUIRED CHARACTERISTICS OF MEDIUM-POWER TELEVISION AERIALS

2.1. General

The requirements stated here are those finally decided upon. They differ in several respects from those existing when the long slot was first considered for use at these stations.

Horizontally-polarized aerials are required for the following stations:

Channel 1,	45 Mc/s	Divis
Channel 4,	61·75 Mc/s	Meldrum
Channel 5,	66·75 Mc/s	Pontop Pike

The frequencies quoted are for the vision carriers. Vestigial-sideband transmission will be used; the band over which the performance of the aerial is specified extends from 3 Mc/s below the vision carrier to 0·75 Mc/s above it. The sound carrier will be 3·5 Mc/s below the vision carrier.

2.2. Gain

The "effective gain" is the gain of the aerial, with its feeder, relative to a half-wave dipole supplied by a lossless feeder; loss in the sound-vision combining network is assumed to be negligible. The gain computed from radiation-pattern measurements, which does not take feeder loss into account, will be termed the "aerial intrinsic gain".

The effective gain, averaged over the horizontal radiation pattern, is to be at least 6 dB at the vision carrier frequency and 5 dB at the sound carrier frequency. At each carrier frequency the gain in any horizontal direction is not to differ from that in any other horizontal direction by more than 3 dB.

In any horizontal direction the difference in decibels between the gain at any frequency f Mc/s and that at the vision carrier frequency f_c Mc/s is not to exceed $0{\cdot}1 + \frac{1}{3}(f \sim f_c)$. Only values of f within the vision band $(f_c - 3) < f < (f_c + 0{\cdot}75)$ need be considered.

The intrinsic gain required depends upon the feeder loss. The feeder to be used is Telcon HM7AL semi-air-spaced cable, which, assuming a length of 500 ft, will have a loss of 1·1 dB. It follows that the mean intrinsic gain at the vision carrier frequency must be at least 7·1 dB. No allowance has been made for loss in a vestigial-sideband filter, since it is intended to achieve the required spectrum by adjustment of the transmitter.

2.3. Matching

Research Department Report No. E-046[3] discusses the specification of the impedance-frequency characteristic of a television transmitting aerial. Alternative specifications are expressed in terms of the maximum permissible level of delayed-image radiation; the method of deducing the permissible reflection at the aerial, taking into account feeder loss and imperfect reflection at the transmitter, is described. The most easily satisfied specification is that in which the delayed signal is allowed to increase by 18 dB from the vision carrier to the edge of the lower vision sideband. For a feeder loss of 1·1 dB (2·2 dB in the two additional traversals of the feeder made by the reflected wave), the maximum reflection coefficient is 0·011 at the vision carrier frequency f_c, increasing linearly to 0·087 at $f_c - 3$ Mc/s and to 0·062 at $f_c + 0{\cdot}75$ Mc/s.

2.4. Mechanical Requirement

At each station provision is to be made for the possible addition of a high-gain aerial for transmission in Band III, which would be mounted above the Band I aerial. The form which the Band III aerial would take was not decided at the time of this investigation, but it was assumed that it would be a cantilever structure about 60 ft (18·3 m) in height. The Band I aerial must be strong enough to withstand the bending moment which would result.

3. DESCRIPTION OF THE AERIAL

A provisional mechanical design of the full-scale aerial was agreed with Building Department and P. & I.D. before some of the requirements outlined above materialised. The model, illustrated in Figs. 1 and 2, incorporated all the features of this design which were considered likely to affect the electrical performance. Its operating frequency was approximately 200 Mc/s (see Sections 4 and 5, below). In the full-scale aerial the dimensions would be scaled appropriately; for example, an aerial for Channel 1 (45 Mc/s) would be 4·3 times the size of the model.

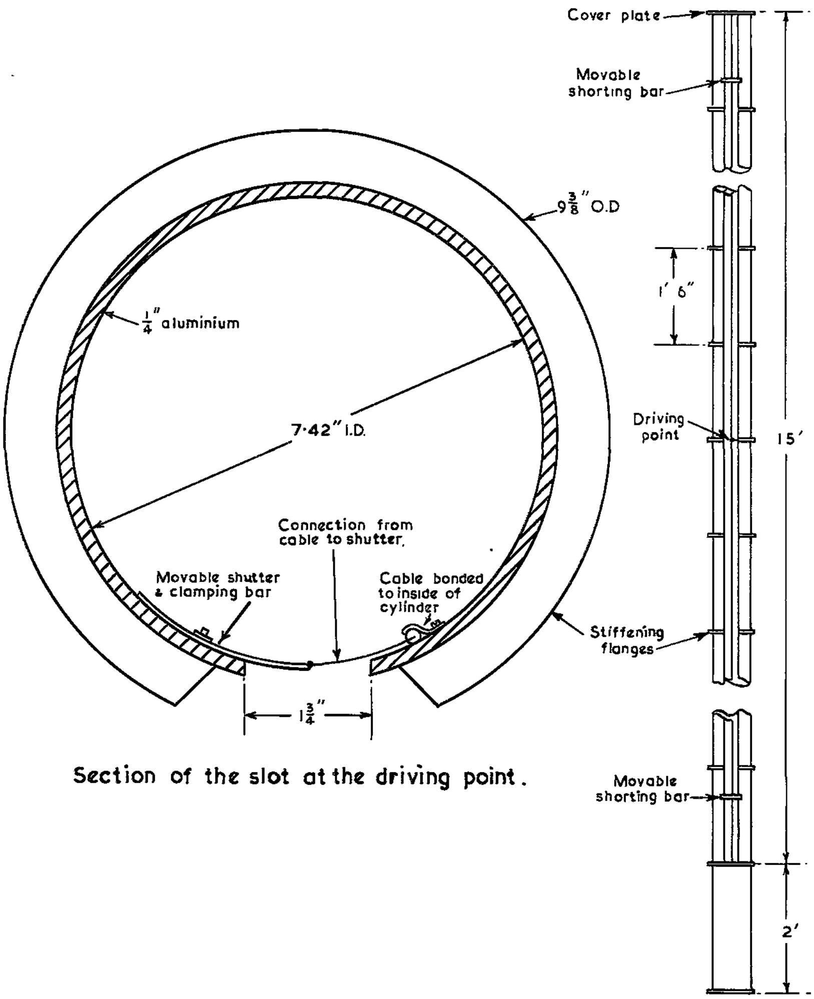

Fig. 1 - The model long-slot aerial

The body of the aerial consisted of 0·25 in. (6·3 mm) aluminium-alloy sheet, rolled into a cylinder 7·9 in. (20 cm) in outside diameter with a longitudinal slot 1·75 in. (4·4 cm) wide. The maximum length of the cylinder was 15 ft (4·57 m), consisting of up to five sections each 3 ft (91·5 cm) long. A flange at each end and in the centre of each section served both to stiffen the cylinder and to facilitate the joining of sections. An additional section 2 ft (61 cm) long acted as a support.

The slot length was adjustable by a movable short-circuiting strip, the maximum value being 14 ft $9\frac{1}{2}$ in. (4·50 m, 2·90λ). The slot width could be adjusted to any value less than 1·75 in. (4·4 cm) by means of a curved metal shutter clamped to the inner surface of the cylinder. A curved Perspex window 1/16 in. (1·6 mm) thick could be fitted to the outside of the slot for weather proofing but preliminary experiments showed its effect to be negligible, and it was therefore omitted during further measurements.

The slot was energised by means of a 70-ohm coaxial cable (PT29MU), which

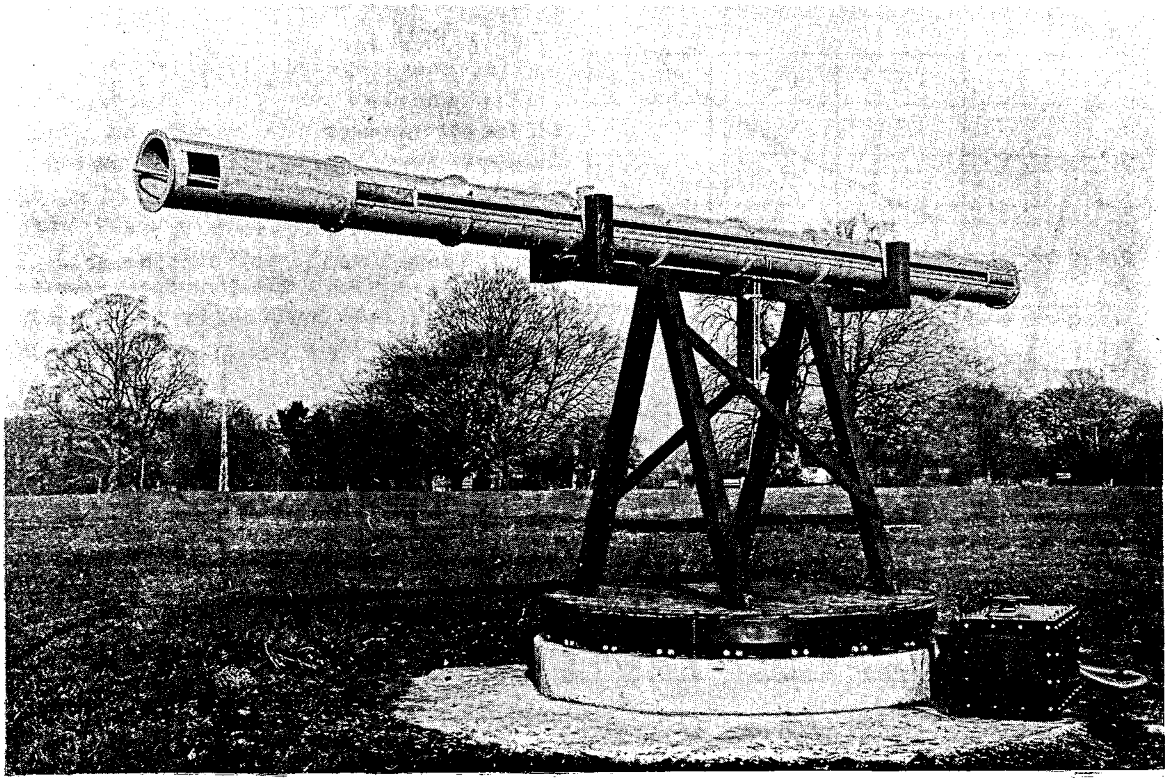

Fig. 2 - Aerial mounted for vertical radiation pattern measurement

was laid in contact with the inner surface of the cylinder near to the edge of the slot. The cable ran from one end of the cylinder to a point level with the centre of the slot. There the outer conductor was bonded to the cylinder, while the inner was connected to the opposite edge of the slot, i.e. to the movable shutter.

4. METHOD OF ADJUSTMENT AND ORDER OF MEASUREMENT

Since it was known that the attainment of a satisfactory impedance-frequency characteristic would become less difficult as the cylinder diameter increased, the mid-band frequency for the measurements was chosen to be the highest giving a sufficiently uniform horizontal radiation pattern. Other aspects of the performance were then investigated for different slot lengths.

For each slot length the width was adjusted to give the maximum power gain. This condition was known to occur when the distribution of voltage along the slot resembled approximately the distribution of current on a full-wave dipole. Thus for a slot length of 2 wavelengths the optimum width would result in a velocity of propagation approximately equal to twice that of light. The slot width was therefore set approximately by observing the voltage distribution, and the exact setting was then determined by measuring the vertical radiation pattern at a number of frequencies, deducing the gain, and choosing the width so as to make the maximum value occur at the carrier frequency. Fig. 3 shows the optimum width as a function of the length.

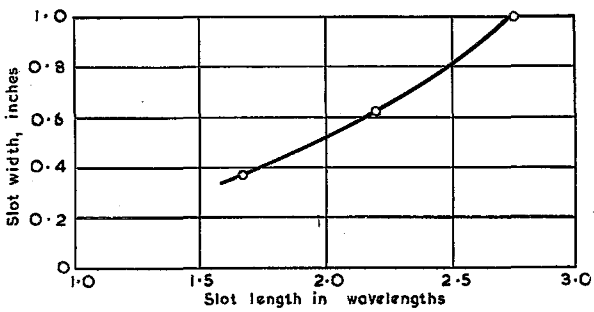

Fig. 3 - Slot width for maximum gain

In addition to the measurements with the width set for optimum gain, some impedance measurements were also carried out for other widths. Since, however, it was found that a useful improvement in the impedance-frequency characteristic could not be obtained by sacrificing gain in this way, these results are omitted from the report.

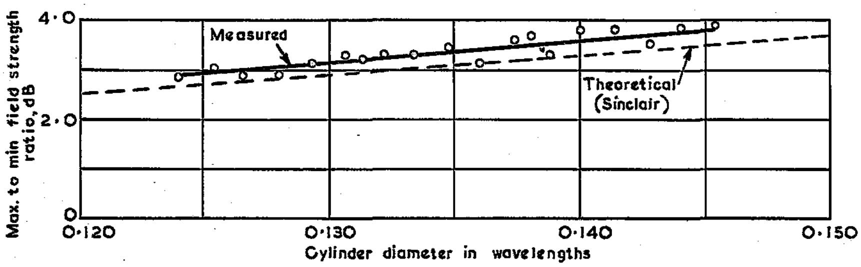

Fig. 4 - Ratio of maximum/minimum field strength in the horizontal plane

5. HORIZONTAL RADIATION PATTERN

This was measured at a number of frequencies by means of a remotely-controlled turntable, the aerial under test being used for reception. In Fig. 4 the ratio of maximum-to-minimum field strength is plotted against the diameter of the cylinder in wavelengths. The measured ratios are in reasonable agreement with theoretical results obtained by Sinclair[4]. The greatest maximum/minimum ratio permitted, 3 dB, is obtained for a cylinder diameter of 0·129λ, corresponding to a frequency of 194 Mc/s. This was therefore assumed to correspond to the vision carrier frequency in subsequent experiments. Since the uniformity of the horizontal radiation pattern improves with decreasing frequency, satisfaction of the specification at the vision carrier frequency implies that it will be met at the sound carrier frequency also.

The shape of the horizontal radiation pattern at 194 Mc/s was in good agreement with that obtained previously by means of a smaller model (Fig. 4 of Research Department Report No. E-039[1]).

6. GAIN

Vertical radiation patterns were measured in two planes, one containing the centre-line of the slot, and the other at 60° to it. Since the patterns were found to differ but slightly with azimuth, a mean pattern was drawn and used for gain calculations. As an example, Fig. 5 shows the measured vertical radiation patterns

and the mean pattern for a slot length of 2·2λ, the width being set according to Fig. 3 for maximum gain.

Fig. 6 shows the mean aerial intrinsic gain as a function of the slot length. It will be seen that the maximum gain is 3·8 dB, obtainable with slot lengths between 2·0λ and 2·2λ. This is in agreement with the results obtained on the smaller model described in Research Department Report No. E-039[1].

Calculations have been carried out to determine the gain of an aerial consisting of two long slots, each 2·0λ in length, with their centres spaced 2·2λ apart. The intrinsic gain was found to be 6·2 dB, an increase of 2·4 dB over a single long slot. The slot width assumed was that giving the greatest gain for a single slot; it is possible that the optimum width for a two-stack aerial would be different. This point was not pursued, since the aerial had been designed mechanically for use in a single stack only. It seems likely that considerable modification would be required to enable one long-slot aerial to support the load imposed by another, in addition to a Band III aerial, above it.

The limit set in Section 2·2 for the variation of gain with frequency is not exceeded. As an example Fig. 7 shows the aerial intrinsic gain as a function of frequency and azimuth for a 2·2λ slot.

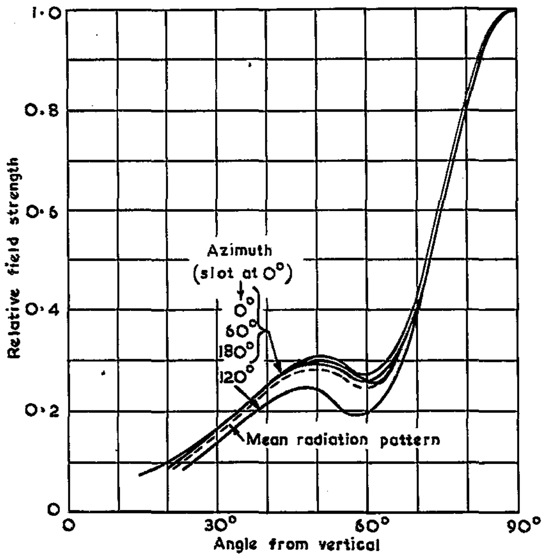

Fig. 5 - Vertical radiation patterns for a 2·2λ slot

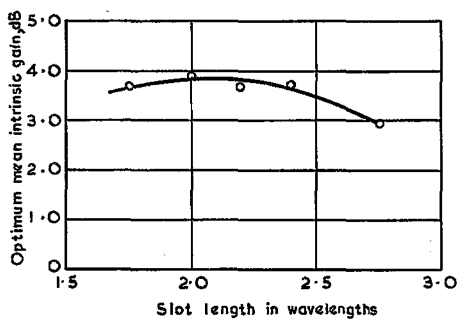

Fig. 6 - Variation of mean intrinsic gain with slot length (width set for maximum gain)

7. MATCHING

Admittance was measured by means of a General Radio U.H.F. Admittance Meter Type 1602A, which was modified for measuring through a 70-ohm cable. A "Telconnector" was fitted in place of the 50-ohm connector with which the admittance meter was supplied. Errors in the admittance meter, and those caused by discontinuities in the cable and connector, were corrected by calibrating the measuring system with known reactances.

Fig. 8 shows the admittance plotted against frequency for three slot lengths: 1·67λ, 2·2λ and 2·75λ. In each case the slot width was set for maximum gain in accordance with Fig. 3. The frequency scales correspond to Channel 1 (Divis) since this channel occupies the greatest percentage bandwidth and presents the greatest matching problem.

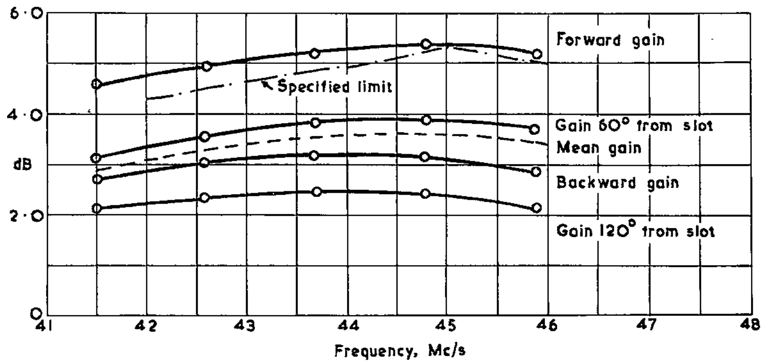

Fig. 7 - Variation of intrinsic gain with frequency
for a 2·2λ slot

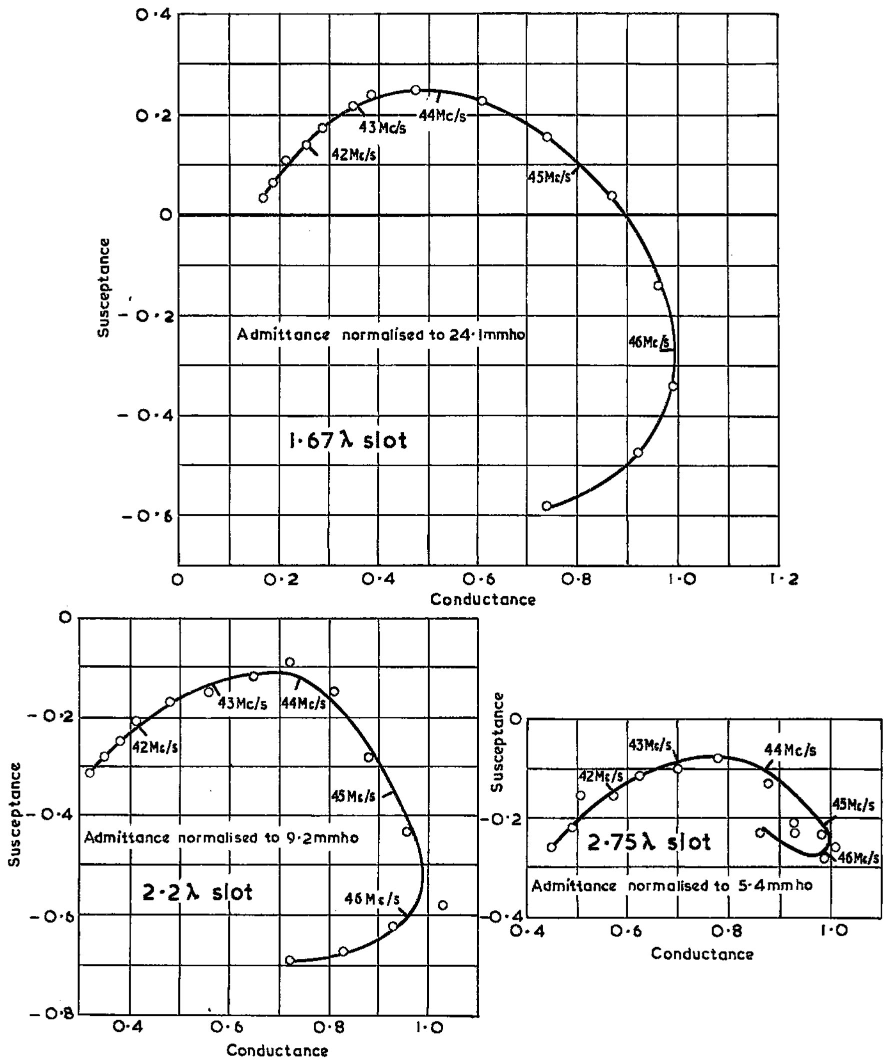

Fig. 8 - Admittance/frequency characteristics for three slot lengths,
normalised to the maximum conductance
(slot width set for maximum gain in each case)

The form of the curves indicates a rapid change of electrical length with frequency. This is to be expected, since the high phase velocity along the slot must be associated with a low group velocity, the geometric mean of the phase and group velocities being approximately equal to the velocity of light. Thus if a 2·2 wavelength slot has an electrical length of one wavelength at the mid-band frequency, the rate of change of electrical length with frequency at the mid-band frequency corresponds to an apparent length of $2{\cdot}2^2/1 = 4{\cdot}8$ wavelengths. The "curled-up" appearance of the curves of Fig. 8 is due to the rapidly changing phase of the reflection from the ends of the slot. This effect, which tends to restrict the impedance bandwidth, is offset to some extent by the fact that the waves reflected from the ends of the slot are heavily attenuated by radiation. The result is that the long slot compares favourably in its admittance-frequency characteristic with a thick dipole of the type proposed for television stations, if neither aerial is reactance- or susceptance-compensated. The long slot is, however, less easy to improve by compensation, owing to the curvature of its admittance-frequency characteristic.

The effect of various types of compensating network upon the admittance-frequency curves of Fig. 8 was calculated. The best result was obtained with the arrangement of Fig. 9. This network, together with the transformer required between it and the feeder, is characterised by ten independent real parameters. We may compare an arrangement for matching at one frequency, which requires two parameters, or a circuit for first-order reactance compensation, which requires four.

Fig. 10 shows the reflection coefficient after compensation, deduced theoretically from the measured slot admittance shown in Fig. 8. In view of the number of parameters characterising the compensating circuit it is by no means certain that the optimum values were found; but since the difficulty of finding them experimentally when adjusting an aerial would be even greater, further effort in calculation did not seem justified.

It will be observed that the $2{\cdot}2\lambda$ slot fails to meet the specification. The $2{\cdot}75\lambda$ slot would meet the specification if the frequency scale were moved by 0·3 Mc/s. Changes could undoubtedly be made to achieve this result. The $1{\cdot}67\lambda$ slot was not considered in detail since it was clear from an inspection of the admittance curve that there was little prospect of bringing it within the specification.

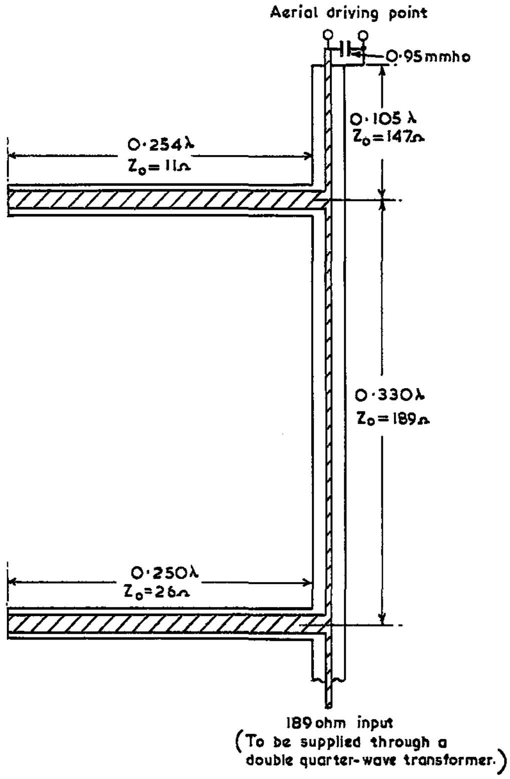

Fig. 9 - Compensating circuits (the dimensions are those required for a $2{\cdot}2\lambda$ slot)

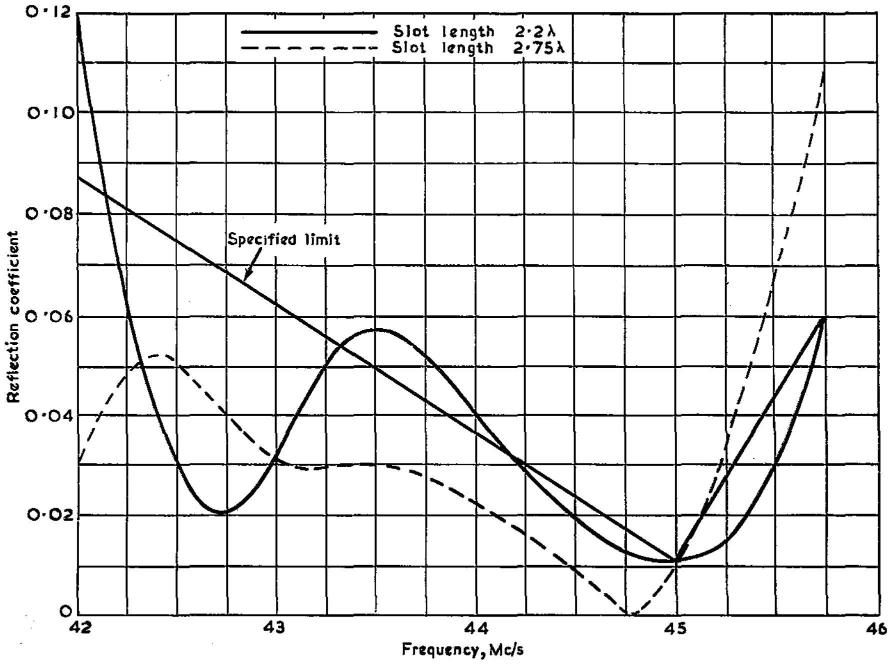

Fig. 10 - Reflection coefficient after compensation, calculated from measured slot admittance (Fig. 8)

8. CONCLUSIONS

The principal merit of the long slot is the fact that it has a gain of over 3 dB over a half-wave dipole, while requiring only a single feed-point. This simplicity is however counterbalanced (in Band I) by the fact that an elaborate compensating network is required to meet the specified limit for the reflection coefficient. This difficulty would not arise if the aerial were used for f.m. broadcasting in Band II or television in Band III.

At the medium-power television stations, where two stacks of the long-slot aerial would be required for Band I, and where a Band III aerial is ultimately to be supported above these, mechanical considerations are of paramount importance. Calculations by Building Department indicated that even for a single long-slot aerial, 0·875 in. (2·2 cm) steel plate would be required. In Channel 1 (45 Mc/s) the weight would be at least six tons. It is not known what the weight of the lower long-slot aerial at a medium-power station would be, but the cost of the complete installation, including erection, would clearly be very great.

The complexity of the admittance-compensating network, together with the mechanical difficulty referred to above, led to a decision to abandon the long slot for the medium-power television stations. Nevertheless, should a simple aerial with an intrinsic gain of 3-4 dB be required for Band II or Band III, the long slot would merit further consideration.

9. REFERENCES

1. "Interim Report on the Long-Slot Aerial", Research Department Report No. E-039.

2. "Second Interim Report on the Long-Slot Aerial", Research Department Report No. E-039/2.

3. "Specification of the Impedance Characteristics of Television Transmitting Aerial Systems", Research Department Report No. E-046.

4. Sinclair, G., "The Patterns of Slotted-Cylinder Antennas", Proc. I.E.E., Vol. 36, p.1487, December 1948.

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